Opportunities for Nuclear Energy

January 11, 2012

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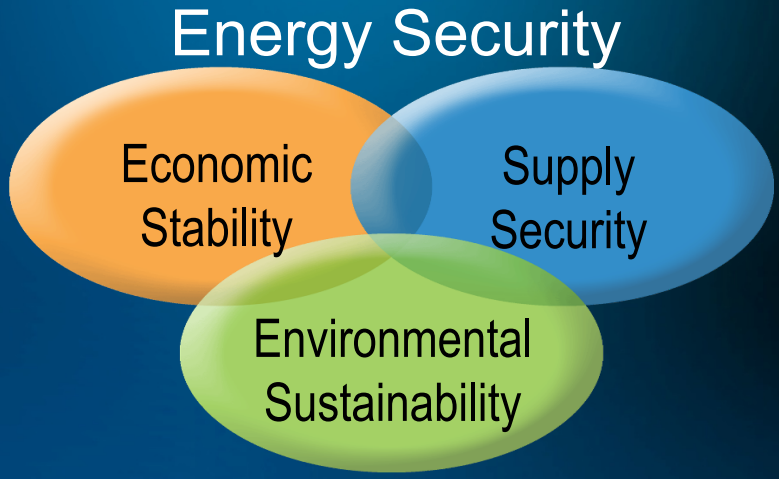
www.inl.gov

Idaho National Laboratory



Market and National Interests Driving Toward Greater Energy Systems Integration

GE's new triple-threat hybrid power plant technology selected to go up in Turkey

New York Times, April 11, 2012
"At the University of Wyoming, Mark A. Northam, director of the School of Energy Resources and a former scientist and researcher at Mobil and then Exxon Mobil, **points to research into new hybrid energy systems.** Wyoming would like to convert its vast reserves of coal into something more valuable. His university is working with the Idaho National Laboratory to develop a refinery that would turn coal into liquids, which could substitute for oil. "

Equity Fund Backing Renewable-Gas Hybrid Projects

Energy Investors Funds, a pri- ıte equity fund with investments in ımerous high-profile power-sector ·ojects, and NTE Energy LLC jointly ınounced Monday the formation of joint venture to develop and oper- e large-scale "hybrid energy" projects :ross the country combining different pes of renewable and conventional en- gy technologies.

In a statement announcing the cre- ation of EIF-NTE Hybrid Renewable Energy LLC, the companies said the purpose of the joint venture is to deploy new sources of electric power that cost less than traditional renewable energy resources such as wind and solar.

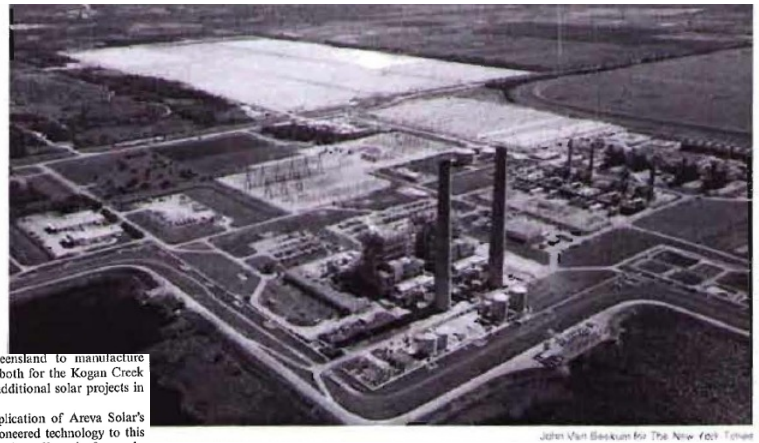
To produce hybrid energy, the joint venture will build power plants that com- bine solar, biomass and other renewable technologies with natural gas turbine technology. The companies said they plan to site hybrid energy facilities in South Carolina, Alabama and Florida, where NTE, a startup focused on hybrid energy technology, is headquartered.

Energy Investors Funds, which has offices in Boston, New York and San Francisco, has made more than 100 diversified investments totaling more than $15 billion in asset value. The private equity fund is backing, among other projects, the 30-mile, 550-mega- watt undersea power line linking the grids of British Columbia and Wash- ington state.

The Energy Daily
April 8, 2010

CHINESE ACADEMY OF SCIENCES

*The Newest Hybrid Model – FPL Experiments With Solar Thermal ……. **NY Times.com** March 3, 2010*



DARPA

2010 Request for Information / 2012 Proposed Program for Nuclear Energy Driven Mobile Energy Platform (Hybrid)

Areva Announces Solar Project To Boost Aussie Coal Plant

Areva's solar subsidiary announced a deal April 13 to build a 44 megawatt solar thermal unit designed to enhance output at a large coal plant in Queen- sland, Australia, a project that Areva calls the largest solar project south of the Equator and the largest such augmenta- tion project of its type in the world.

Areva's project will use a proprietary "superheated" steam system to boost the steam generation system at the coal-fired Kogan Creek Power Station, owned by Australia's CS Energy. That will boost Kogan Creek's output by up to 44 mega- watts in peak solar conditions above the plant's current capacity of 750 megawatts and will avoid the production of 35,600 tons of greenhouse gas emissions annu- ally, according to Areva Solar.

Areva says it plans to use the Kogan Creek project as a "gateway" to support additional solar thermal project devel- opment in Queensland, an area rich with solar resources.

With that in mind, the French com- pany says it will build a manufacturing plant in Queensland to manufacture components both for the Kogan Creek project and additional solar projects in Australia.

"The application of Areva Solar's Australian-pioneered technology to this utility-scale project affirms its far-reach- ing potential to provide cost-effective, turnkey solutions," Areva Solar Chief Executive Officer Bill Gallo said in a press release announcing the new project.

Areva plans to have the solar aug- mentation unit on-line by 2013, and projects a cost of $113 million.

Areva Solar is a subsidiary of ARE- VA Renewables, which is a unit of Areva Group, one of the world's largest energy companies.

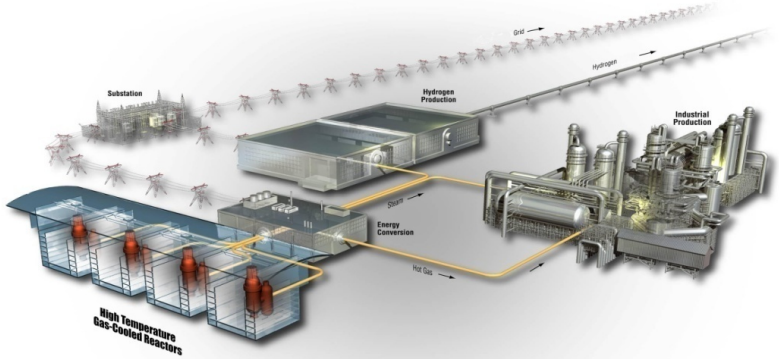
The Energy Daily
April 25, 2011

Implications for Nuclear Energy

- **Market potential for nuclear is constrained, limiting its potential impact in driving energy security, stability, and sustainability solutions. Nuclear energy should be integrated into broader energy markets.**
- **Accelerated integration of renewable energy, particularly non-dispatchable electric generation, is a priority. This can be problematic (capacity factor optimization, grid dynamics). Nuclear energy can solve this problem.**
- **The US possesses enormous fossil energy reserves that will be continue to be competitive. Unconventional methane in particular is a game-changer for nuclear.**
- **New "energy networks" should be designed to accommodate a transition in the mix of fuels used, e.g. accommodate a transition in light transportation from liquids to electricity**

"The greatest danger in times of turbulence is not the turbulence; it is to act with yesterday's logic"

— Peter Drucker



U.S. Nuclear Power Development in the 2000's

Joint international development of advanced reactor and fuel cycle technologies

Generation IV International Forum

International cooperation on six advanced reactor technologies

Industry begins submitting COLs

More than 30 new plants under consideration

LWR Sustainability Program

NGNP

Nuclear energy expands beyond electricity generation

Small and medium reactors

Generation IV becomes a reality

GENERATION III

GENERATION III+/IV

2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021 2022 2023 2024 2025

NPPs set a record 788,528 thousand MWh, surpassing the U.S. and international record

Energy Policy Act

- *Loan guarantees*
- *Production tax credits*
- *Risk insurance*

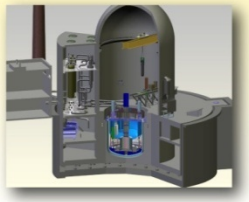
Brown's Ferry I

Restarts after 22 years

By 2008, license extensions approved for half of the reactors, 17 more applications are under review and another 31 applications are expected

By 2008, 5,640 MWe added from uprates

Sodium-cooled fast reactor

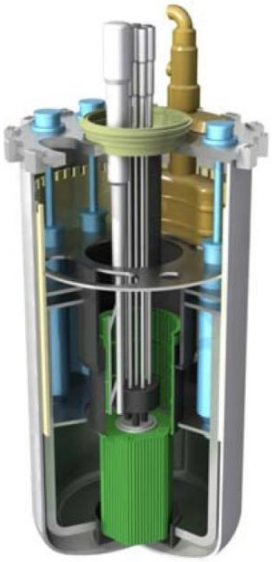


Revolutionary concepts with safety built into design – elegant simplicity

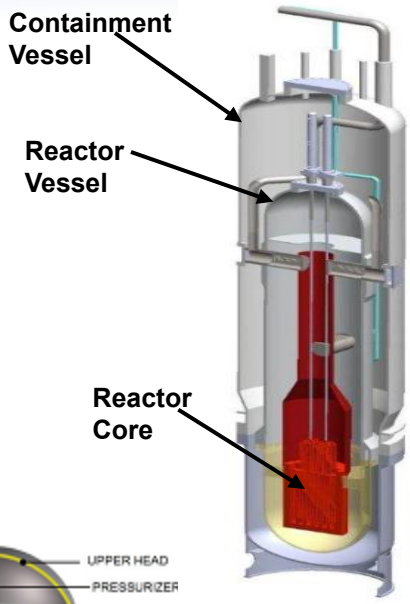
- ***Inherently safe***
- ***Better utilization of fuel resources***
- ***Sustainability***
- ***Improved proliferation resistance***
- ***Growth necessitates new fuel cycle approaches and technology (actinide recycling)***

The Small Modular Reactor (SMR)

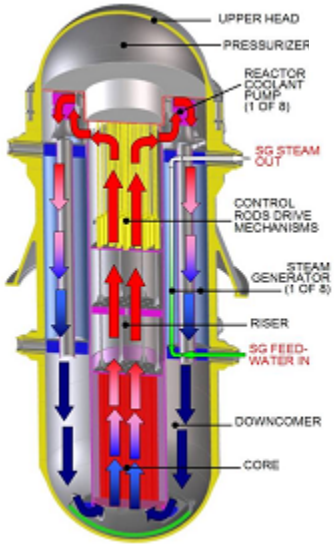
- **IAEA: Less than 300 MWe**
- **Motivated by:**
  - "Forgiving" safety characteristics
  - Eliminate major accident types (integral components)
  - "Factory fabrication"
  - Smaller capital outlay / favorable timing
- **Applications**
  - Smaller load communities (international and domestic)
  - Augment renewable energy (grid stability)
  - Non-electric applications
- **Challenges**
  - Licensing time line
  - Advanced fuel management
  - Diagnostics / control
  - Etc.



PRISM - General Electric

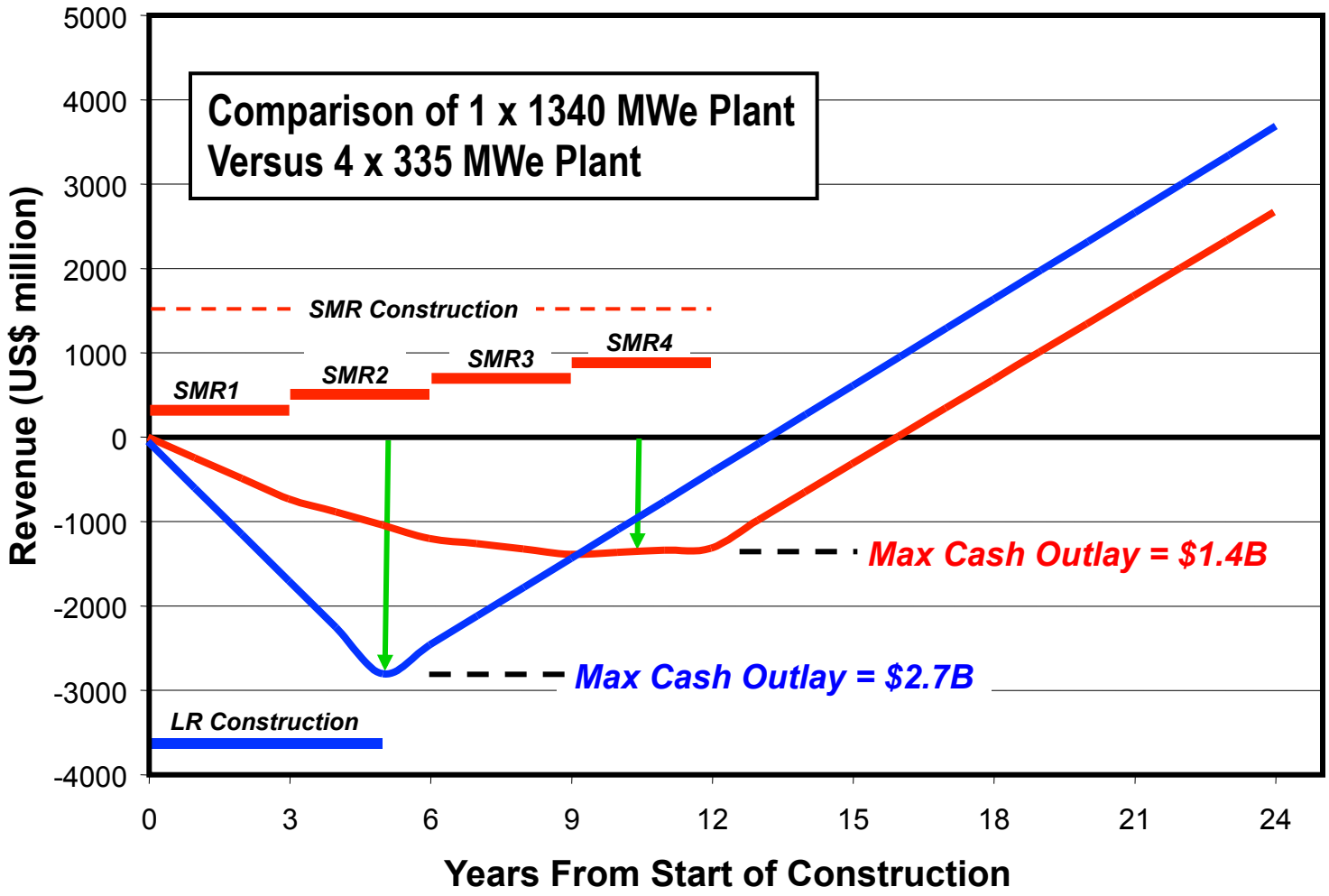


NuScale



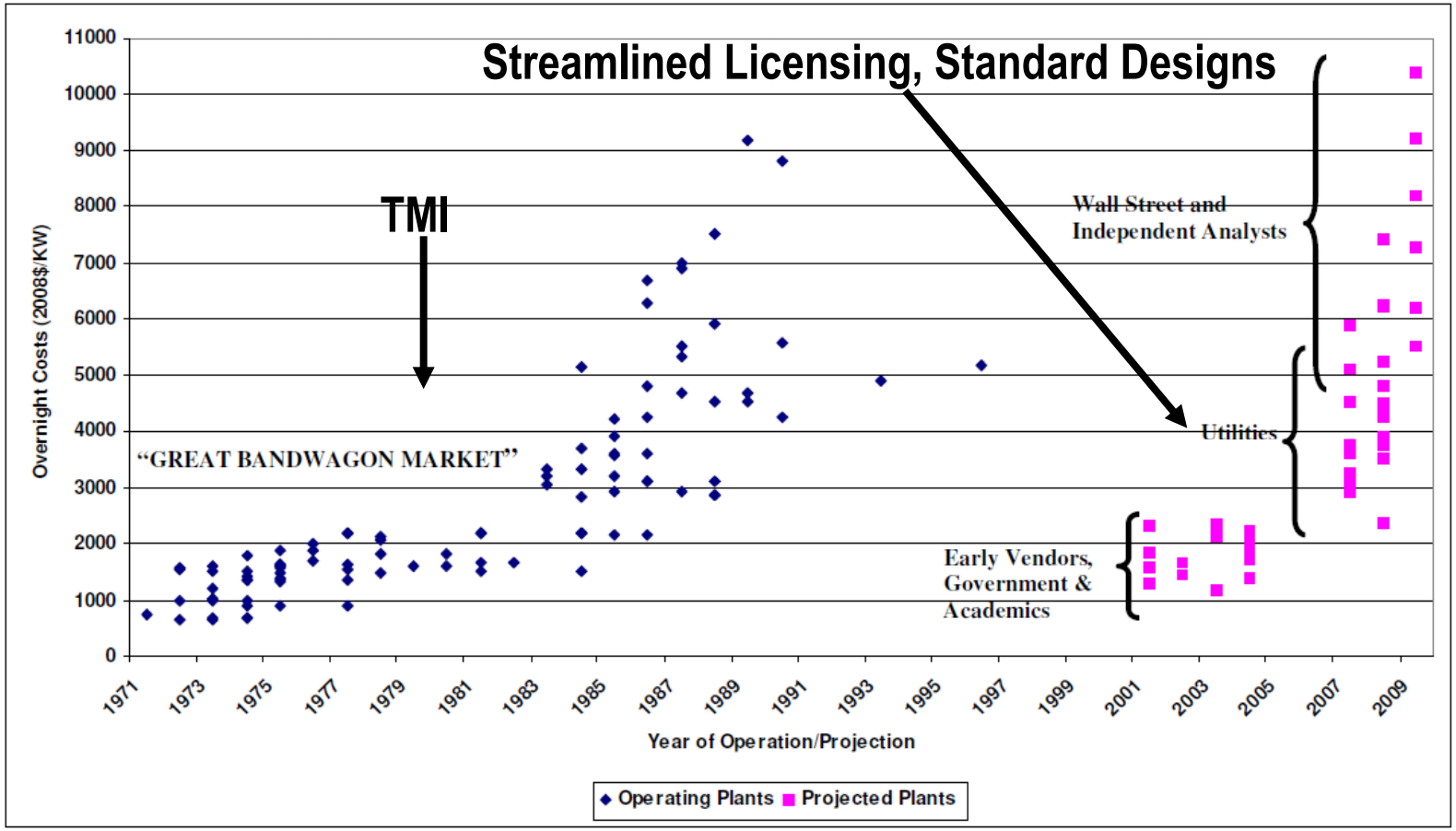
IRIS - Westinghouse

SMR vs. Large Reactors — Trajectory of Capital is Beneficial



Source: B. Petrovic, GaTech

Remember The Past – But It's a Different World Today

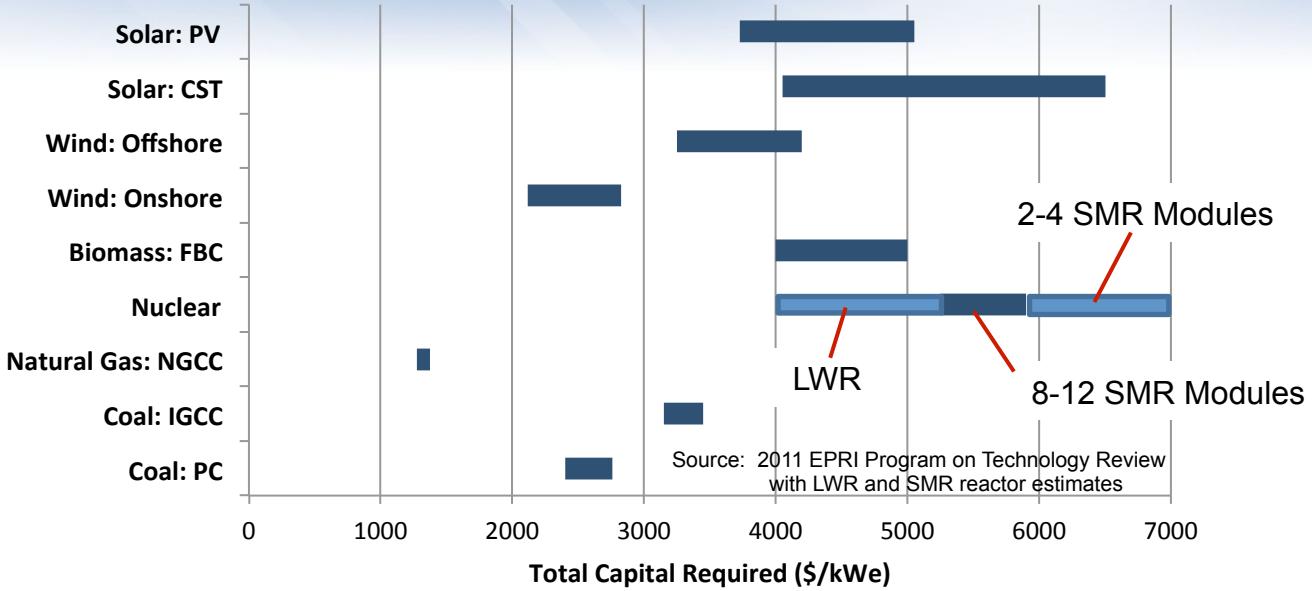


Modified from: The Economics of Nuclear Reactors: Renaissance or Relapse? Mark Cooper, June 2009

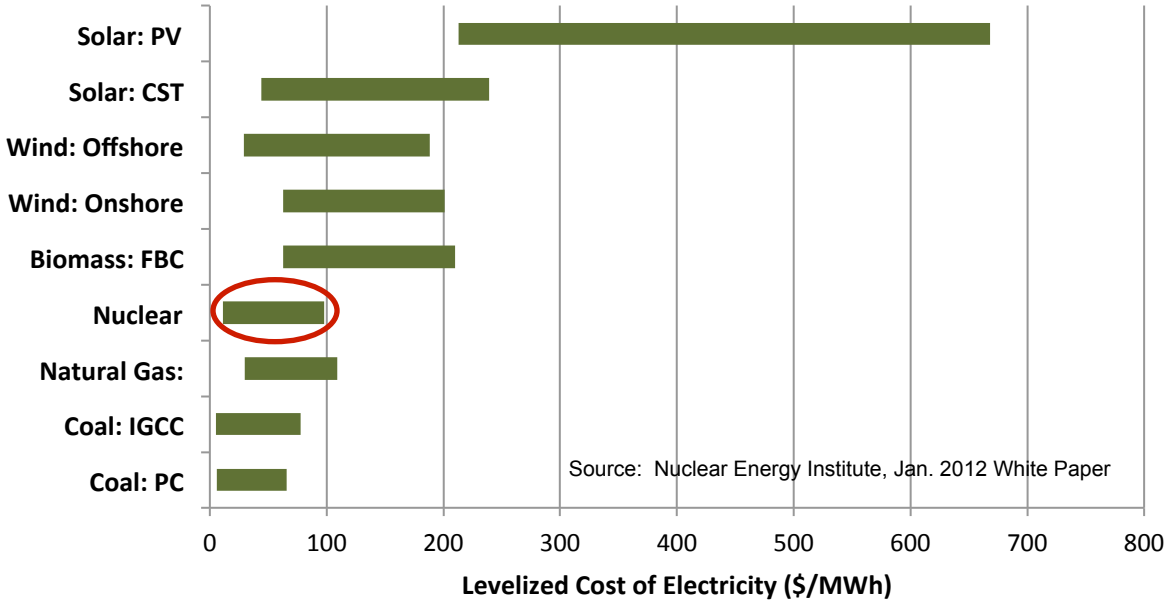
Time & Uncertainty is Risk and Risk is Cost

Clean Electricity Options

Natural gas and coal costs shown do not include carbon capture & sequestration

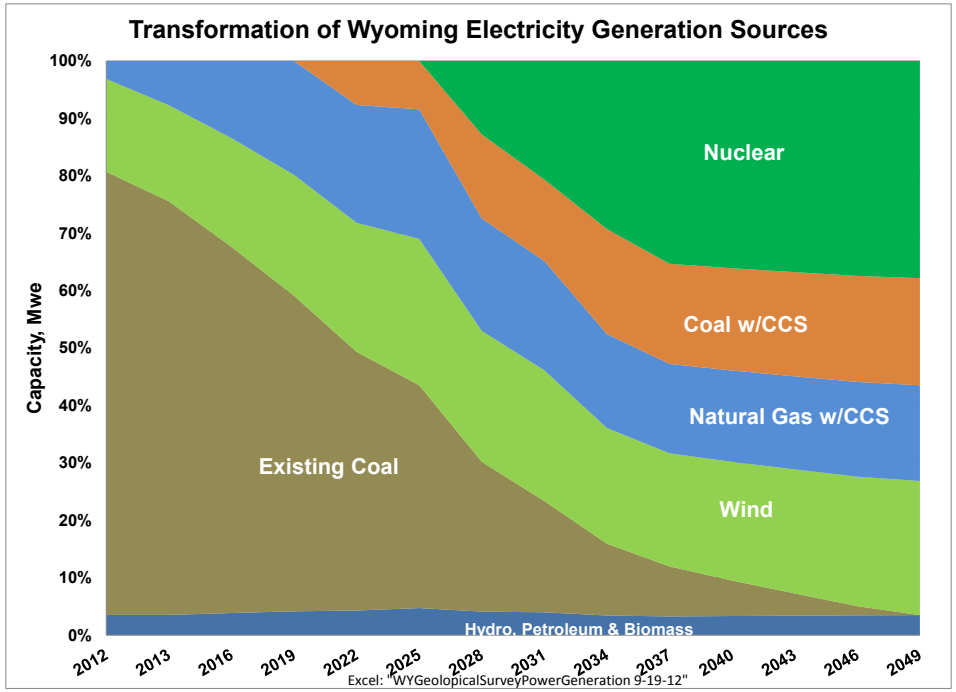


Nuclear energy requires high capital, but has low operating expenses

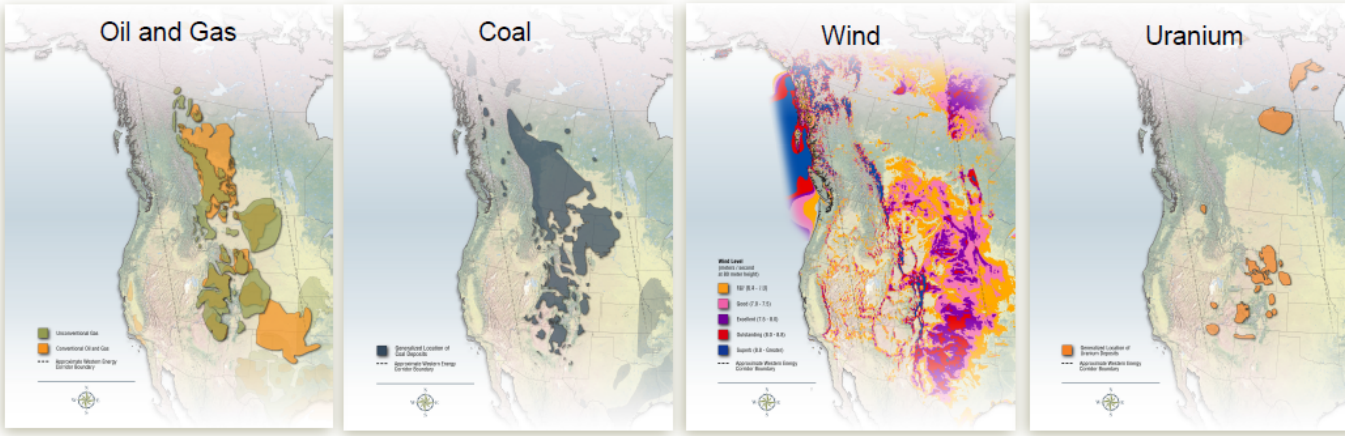


Ensure reliable and affordable sources of energy by diversifying the technologies for generating power

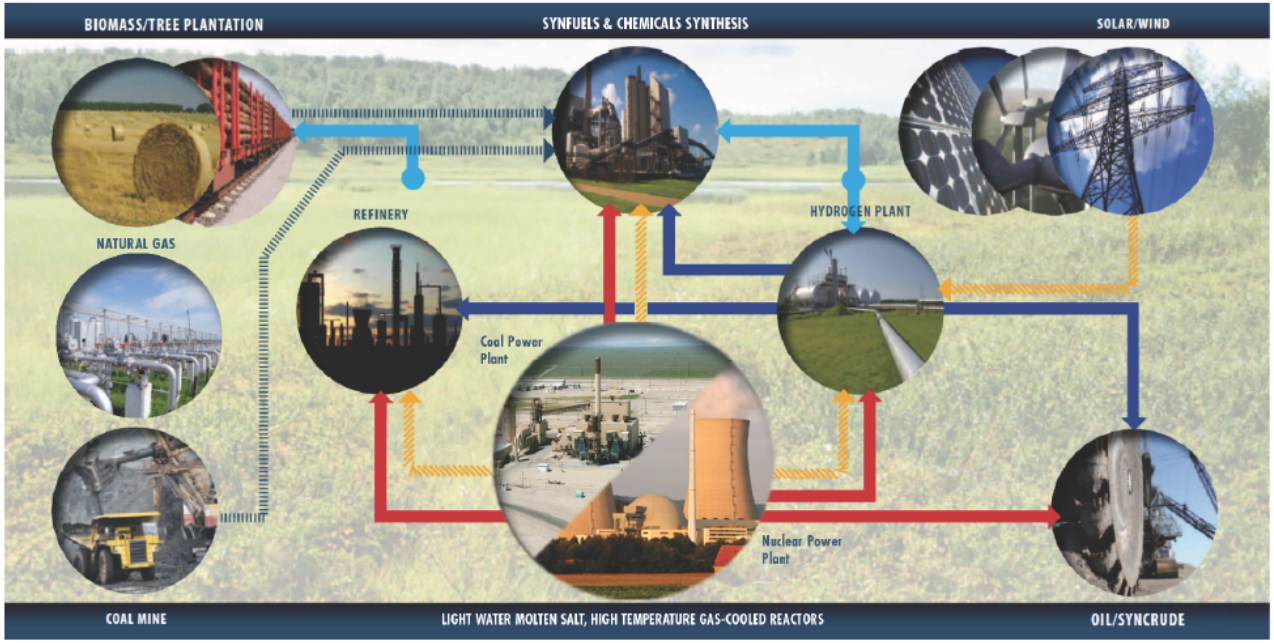
- Notional strategy based on anticipated retirement of ageing existing coal-fired plants
- Initially includes natural gas combined cycle with CCS and renewables; subsequently complemented by clean coal and nuclear energy (e.g. emerging small to medium sized nuclear reactors)
- Nuclear energy (e.g., SMR technology) provides energy for carbon conversion industry as well as electric power



Western Energy Corridor



NREL Wind Resource Data



Co-Gen? Hybrid? What's the Difference?

Thermodynamic Efficiencies

Reactor as "Heat Machine" For General Purposes

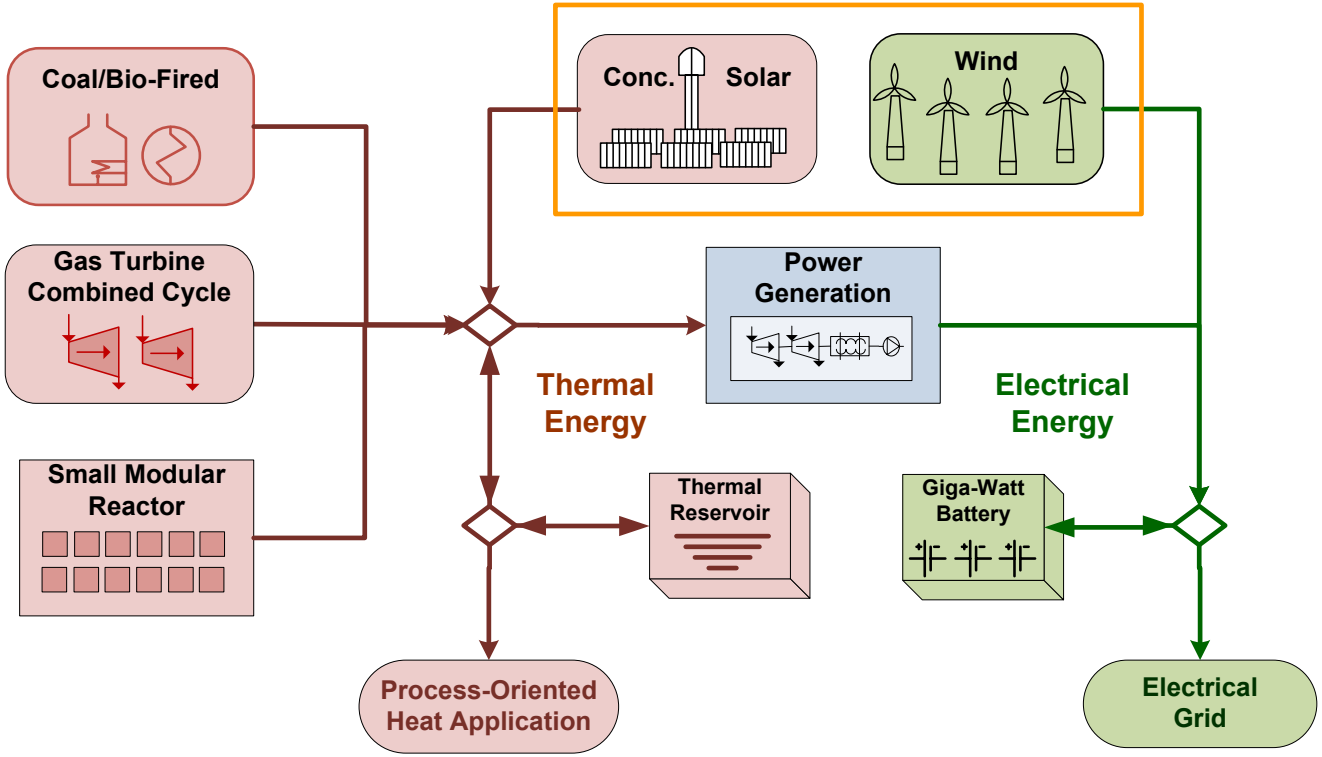
Economic Efficiencies: Capacity Factor and Time-of-Use Value

Integrated Energy System to Make Synthetic Fuels in Quantity

Co-Generation

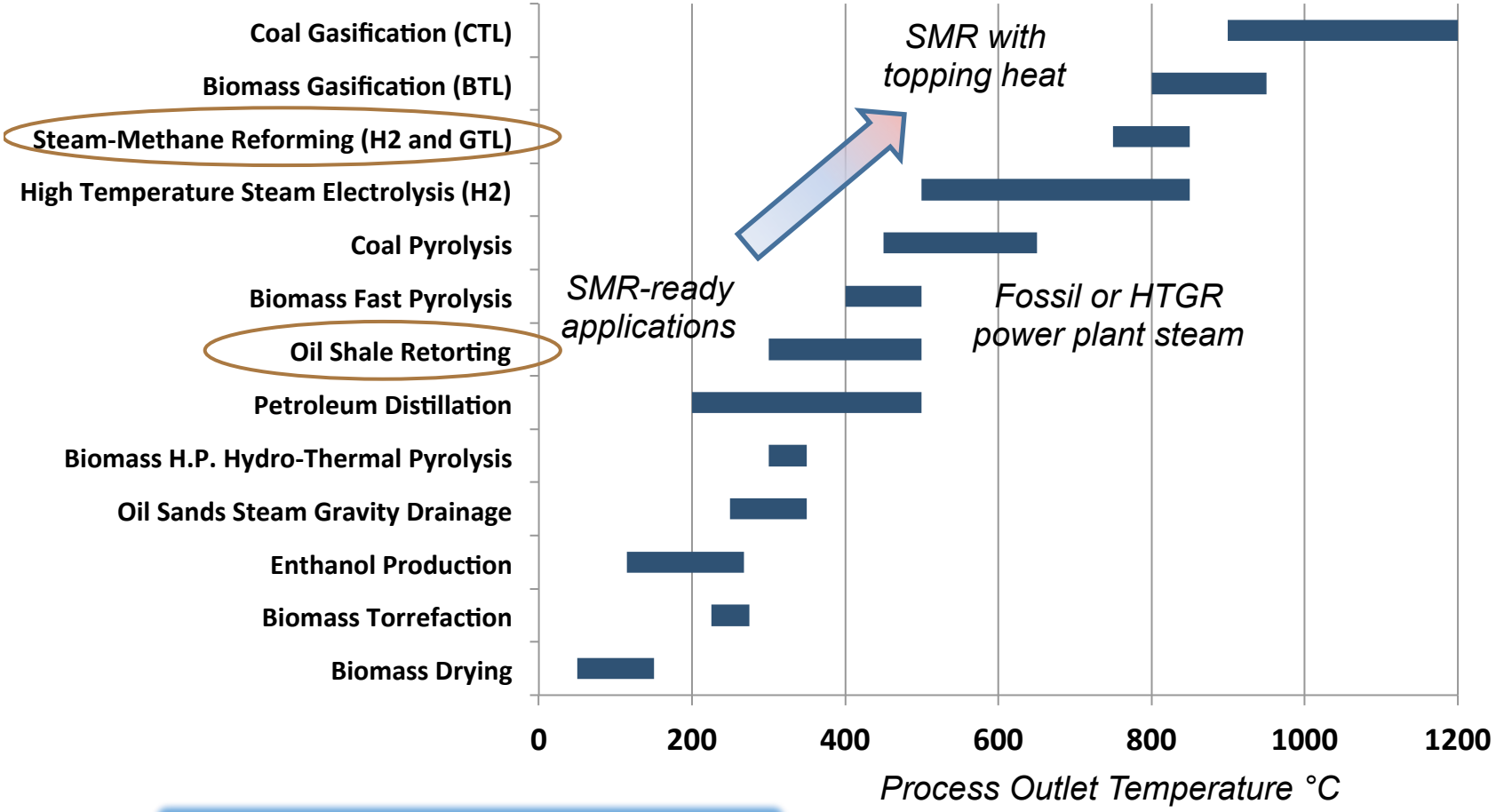
Process Heat Applications

Hybrid Systems

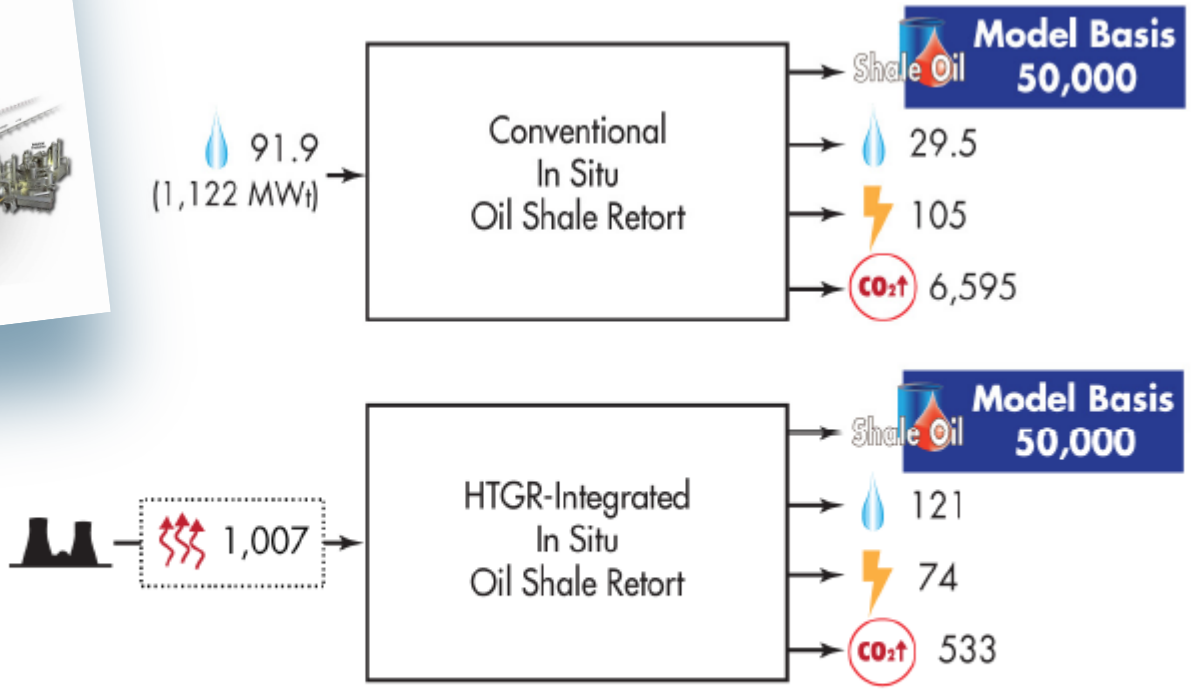


Liquid Fuels Alternatives

Fuels Production Thermal Profile



LWR (SMR) can readily support production of unconventional hydrocarbon fuels



Model Basis:

Shale Oil *(barrels/day)*

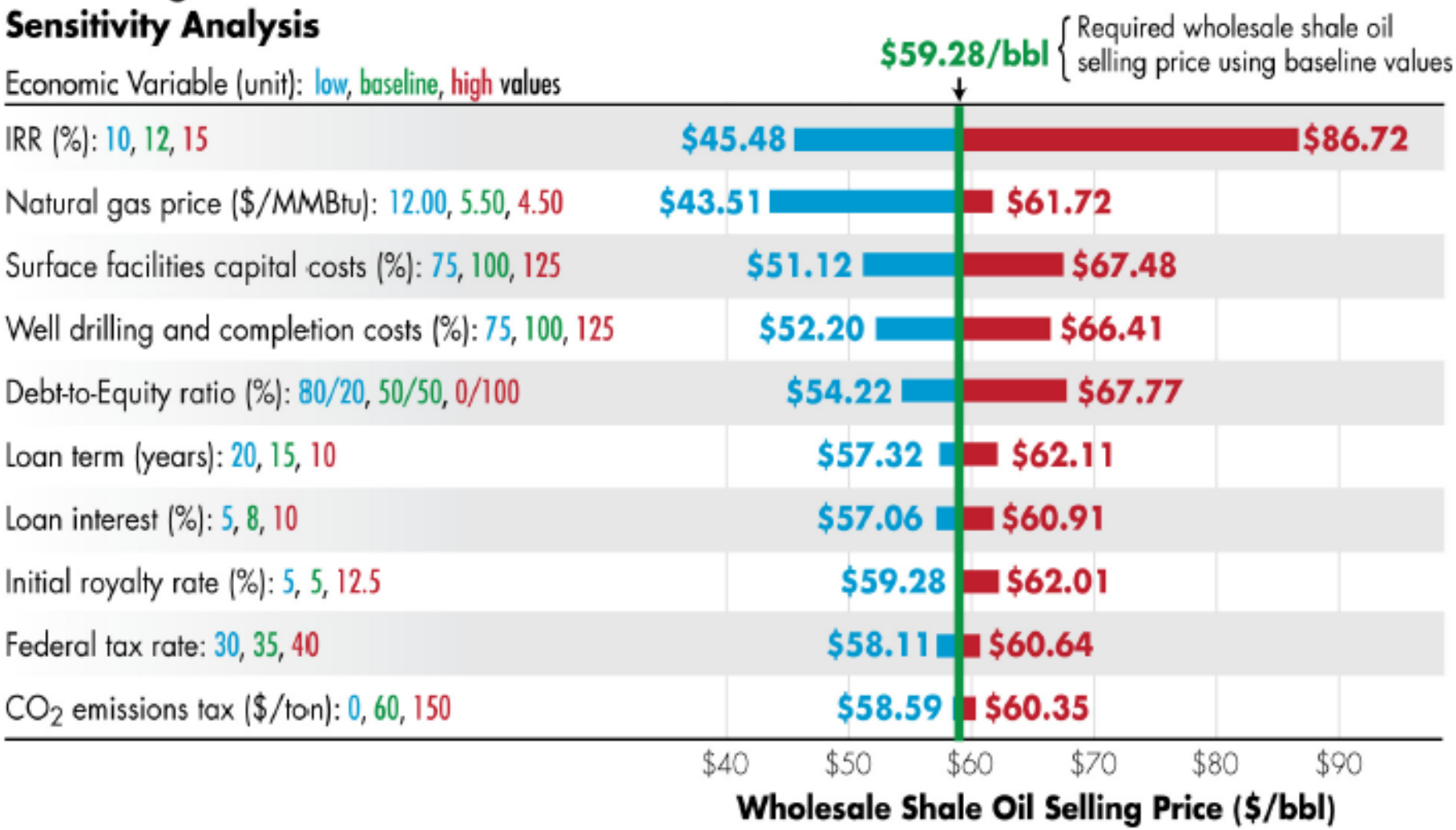
Natural Gas *(billion Btu/day)*

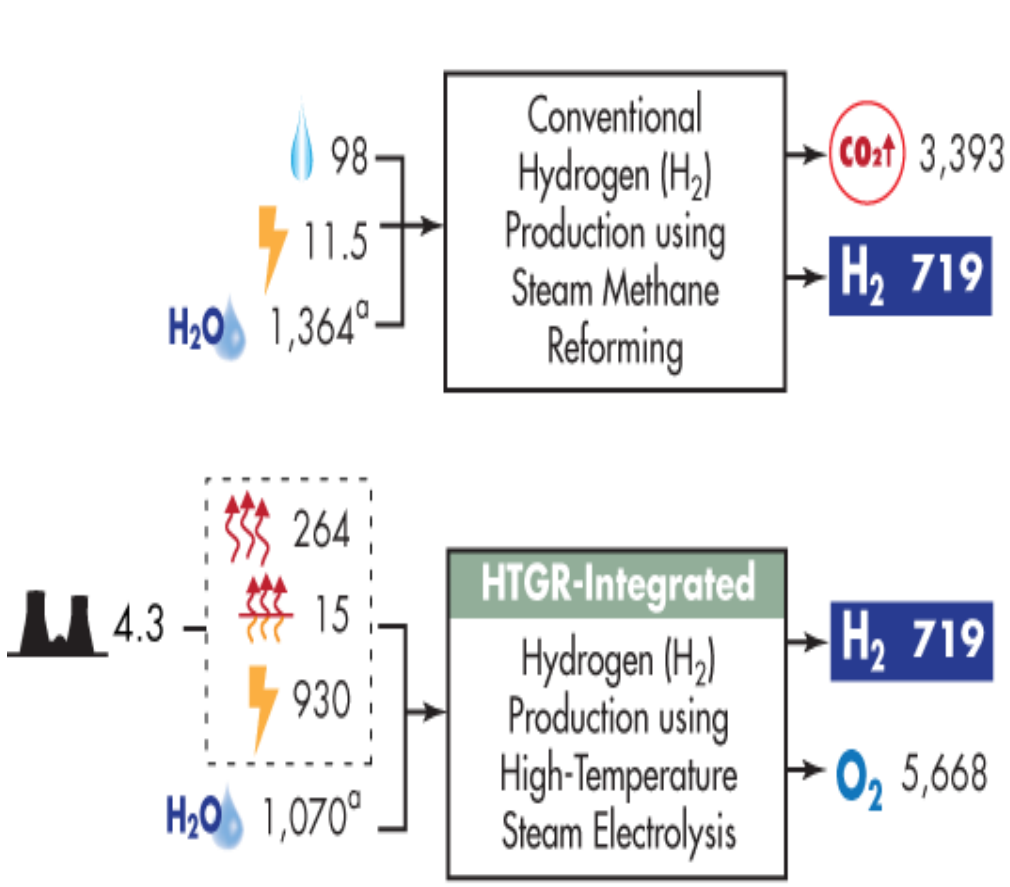
Nuclear Heat *(MWt)*

Electricity *(MW_e)*

Carbon Dioxide Emitted *(tons/day)*

HTGR-Integrated In Situ Oil Shale Retort Sensitivity Analysis



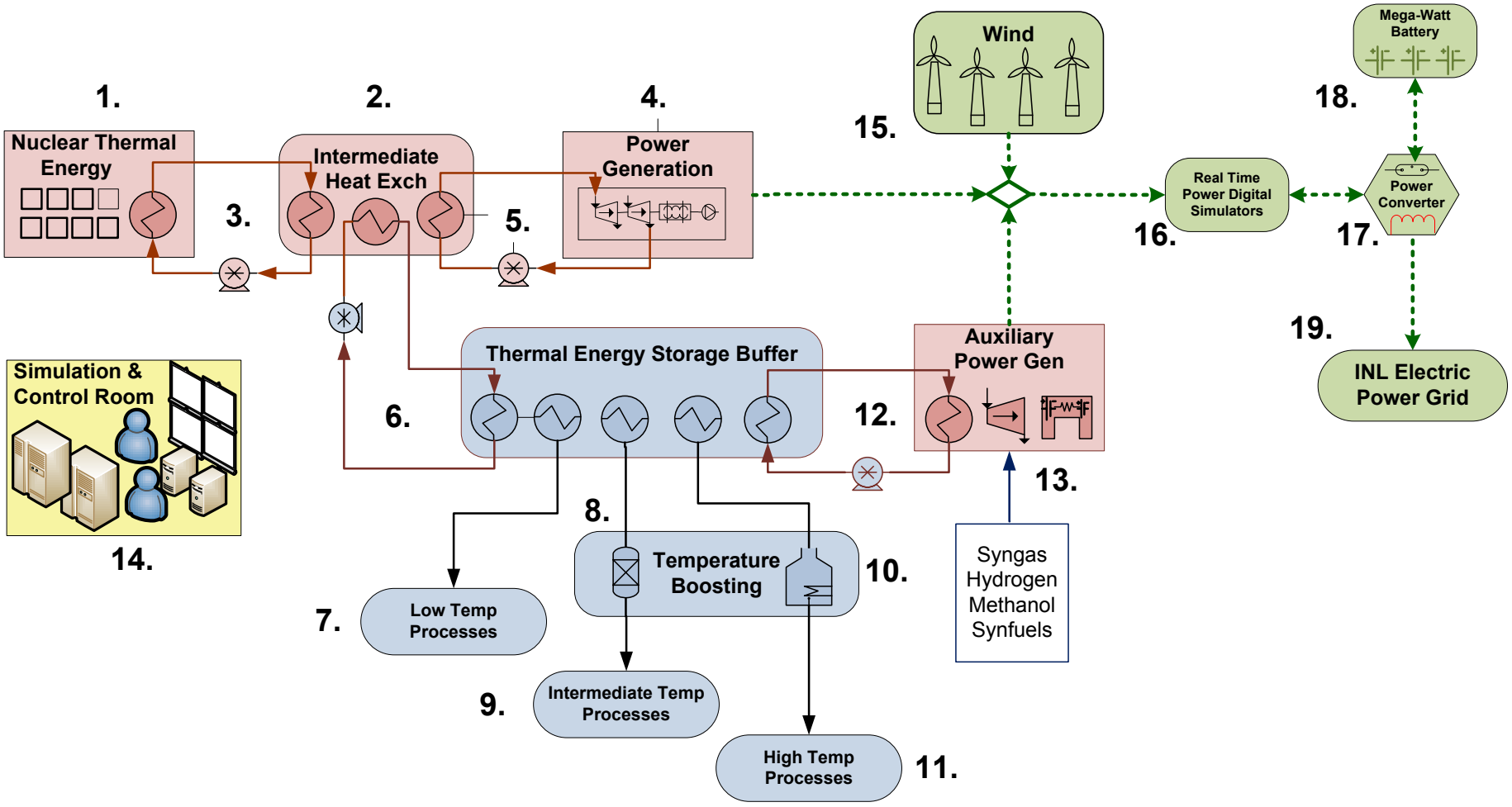


Model Basis:

- H_2 Hydrogen (H_2) *(tons/day)*
- Natural Gas *(millions of cubic feet/day)*
- H_2O Water *(gallons/minute)*
- Electricity *(MW_e)*
- 600-MW_{th} HTGR
- Process Heat *(MW_{th})*
- Topping Heat *(MW_{th})*
- CO_2 Carbon Dioxide Emitted *(tons/day)*
- O_2 Oxygen (O_2) *(tons/day)*

a. Amount needed as feedstock for hydrogen production.

Research, Development, & Demonstration Needs



Demonstration and Testing to Reduce Risk of Deployment (Risk Premium): Wisdom From the Past

Each new concept (academic reactor) generally describes a plant with the following characteristics:

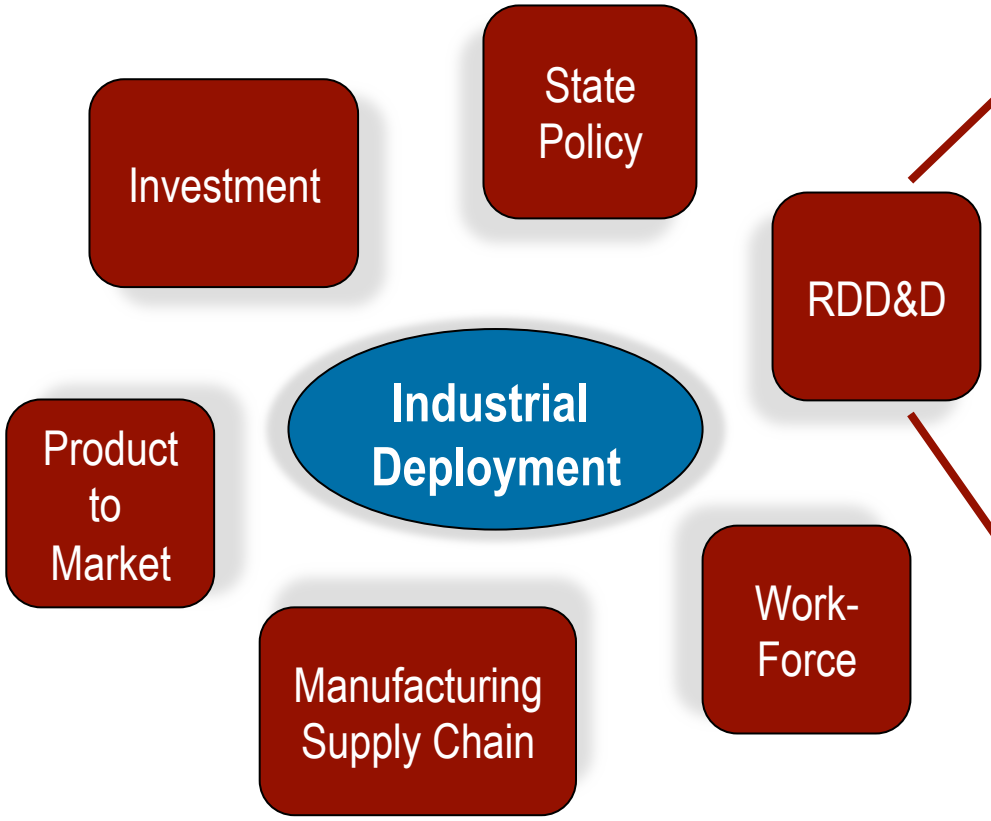
1. **It is simple.**
2. **It is small.**
3. **It is cheap.**
4. **It is light.**
5. **It can be built very quickly.**
6. **Very little development is required. It will use mostly "off-the-shelf" components.**
7. **The reactor plant is in the study phase, it is not being built now.**

A real reactor plant can be distinguished by the following characteristics:

1. **It is being built now.**
2. **It is behind schedule.**
3. **It is requiring an immense amount of development on apparently trivial items.**
4. **It takes a long time to build because of the engineering development problems.**
5. **It is large.**
6. **It is complicated.**
7. **It is heavy.**

Source: "Some Problems in the Applications of Nuclear Propulsion to Naval Vessels," RADM H. G. Rickover, et al, The Society of Naval Architects and Marine Engineers, November, 1957.

Partnerships…



Western States

Industries

National Labs

Research Institutions

*** University Research ***

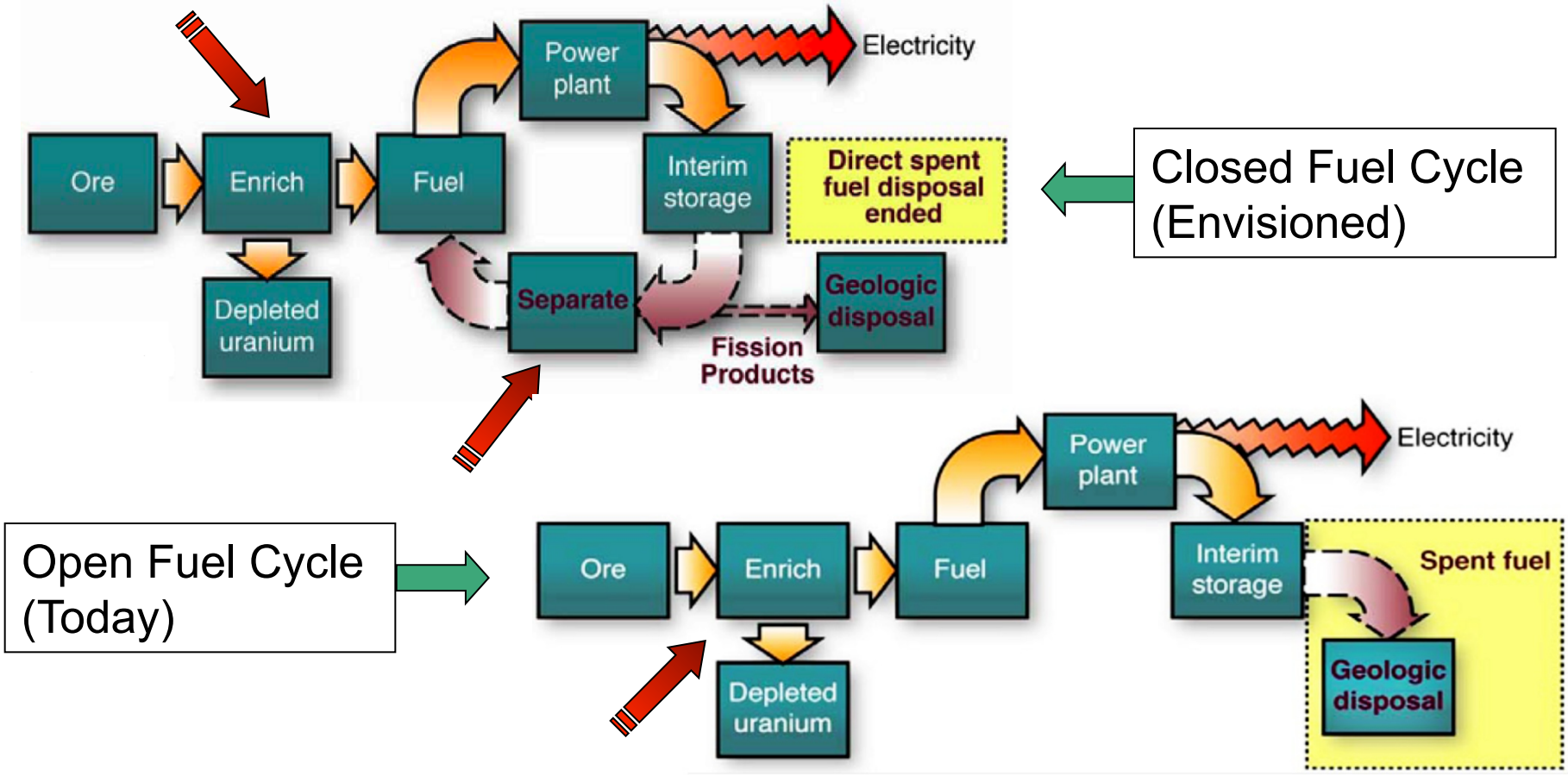
*** Applied R&D ***

*** Pilot Demonstrations ***

*** Commercial Plants ***

EXTRA SLIDES

Elements of a Nuclear Power Fuel Cycle as Envisioned in Early Years & Today



Nuclear reactors are not the primary proliferation risk but rather enrichment and reprocessing, which could be used to produce fissile materials.

Looking to the Future

Optimistic View

- **Countries join together to manage risk**
- **Establish comprehensive fuel services**
  - Countries forgo need for enrichment
  - Countries forgo the vast cost that would be associated with establishing a complete fuel cycle
  - Assurance of fuel supply
  - Eventually, take-back of used fuel
- **Countries work together on nuclear infrastructure needs for developing economies**
  - Physical, human, regulatory, legal, etc.
- **Increased small and medium size reactor options for electricity**
  - 100 – 600 MWe range
- **Eliminates justification for countries to pursue enrichment**
- **With mature technology options, eliminates need for countries to establish civilian R&D programs**

Pessimistic View

- **Autonomous**
- **Nuclear safety and operations could be at risk**
- **Technologies could be deployed that are counter to U.S. proliferation goals**
- **Domestic security of fuel supply would become a key issue for countries'**
- **Fuel cycle capabilities spread**
- **Greater potential for development of clandestine weapons programs**
  - Much easier to develop a nuclear weapon from Highly Enriched Uranium
  - Civilian enrichment program could provide cover for weapons program

In either scenario, nuclear energy will expand around the world. Much depends on how we get there. In the first instance, cooperation combined with adaptability and flexibility would provide resiliency. In the second, control and monitoring would dominate security approaches.